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Fusegi et al.

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(54) **DIFFERENTIAL GEAR MECHANISM**

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Nov. 20, 2001 (JP) P2001-354370
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(51) **Int. Cl.**
F16H 48/20 (2006.01)

(52) **U.S. Cl.** **475/150**; 475/231

(58) **Field of Classification Search** 475/150, 475/231; 192/84.31, 84.92
See application file for complete search history.

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(57) **ABSTRACT**

A differential gear mechanism includes a rotatable case driven by torque from an engine, a differential gear set housed in the case for differential distribution of the torque to a pair of output axes, comprising a first clutch, an annular plunger movable in a direction of the rotation axis and an annular electromagnetic actuator for actuation of the plunger in the direction of the rotation axis. The case further comprises a second clutch being slidable in the direction of the rotation axis and the second clutch is actuated by the plunger so as to be engaged with the first clutch.

16 Claims, 13 Drawing Sheets

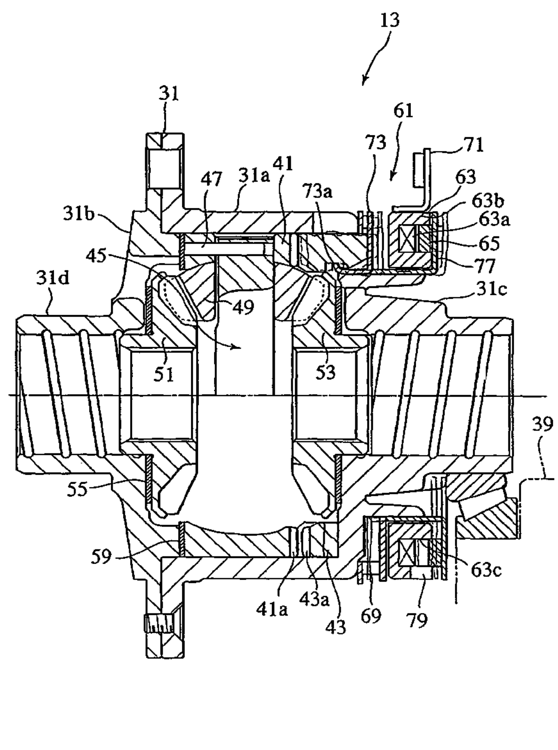


FIG.1

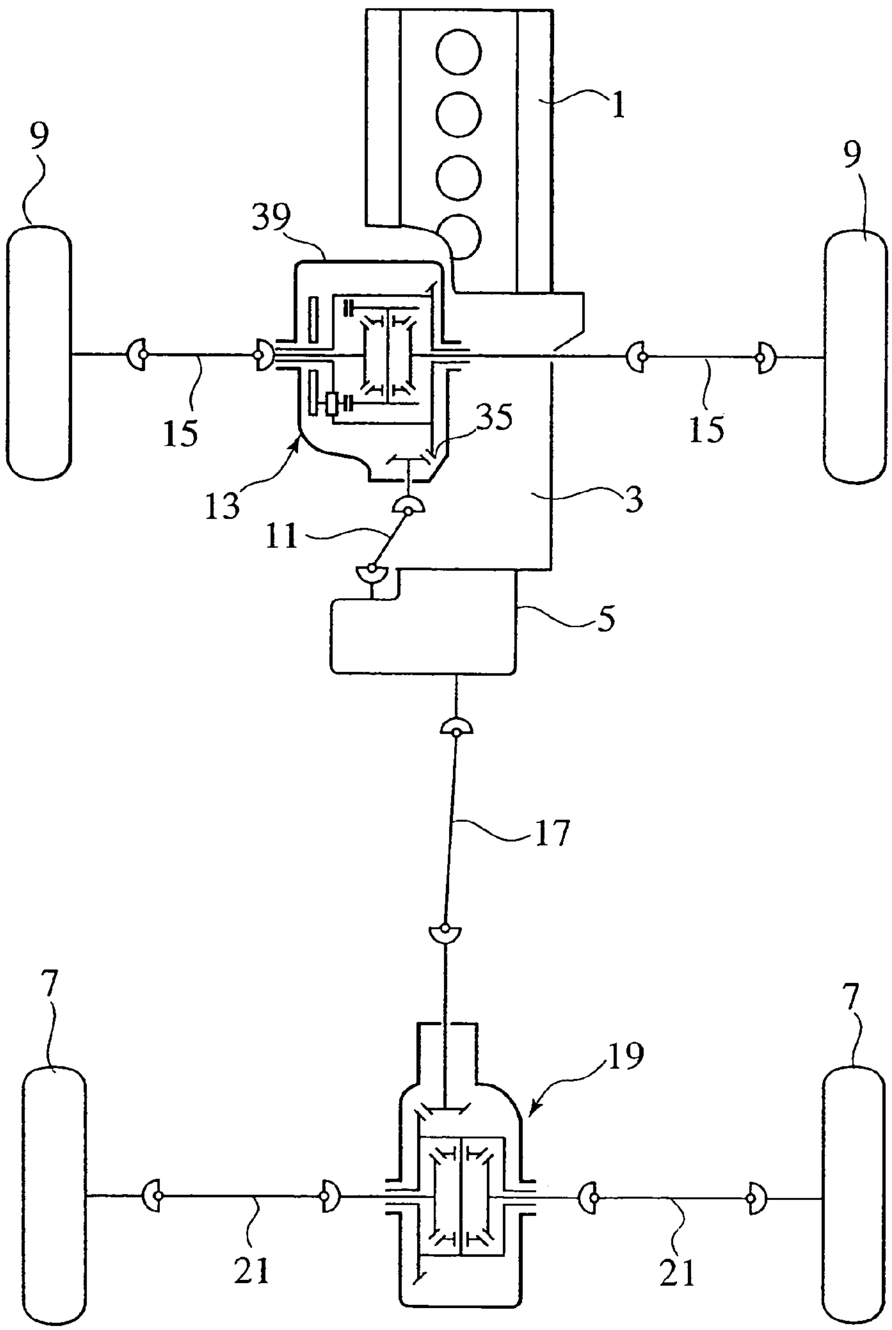
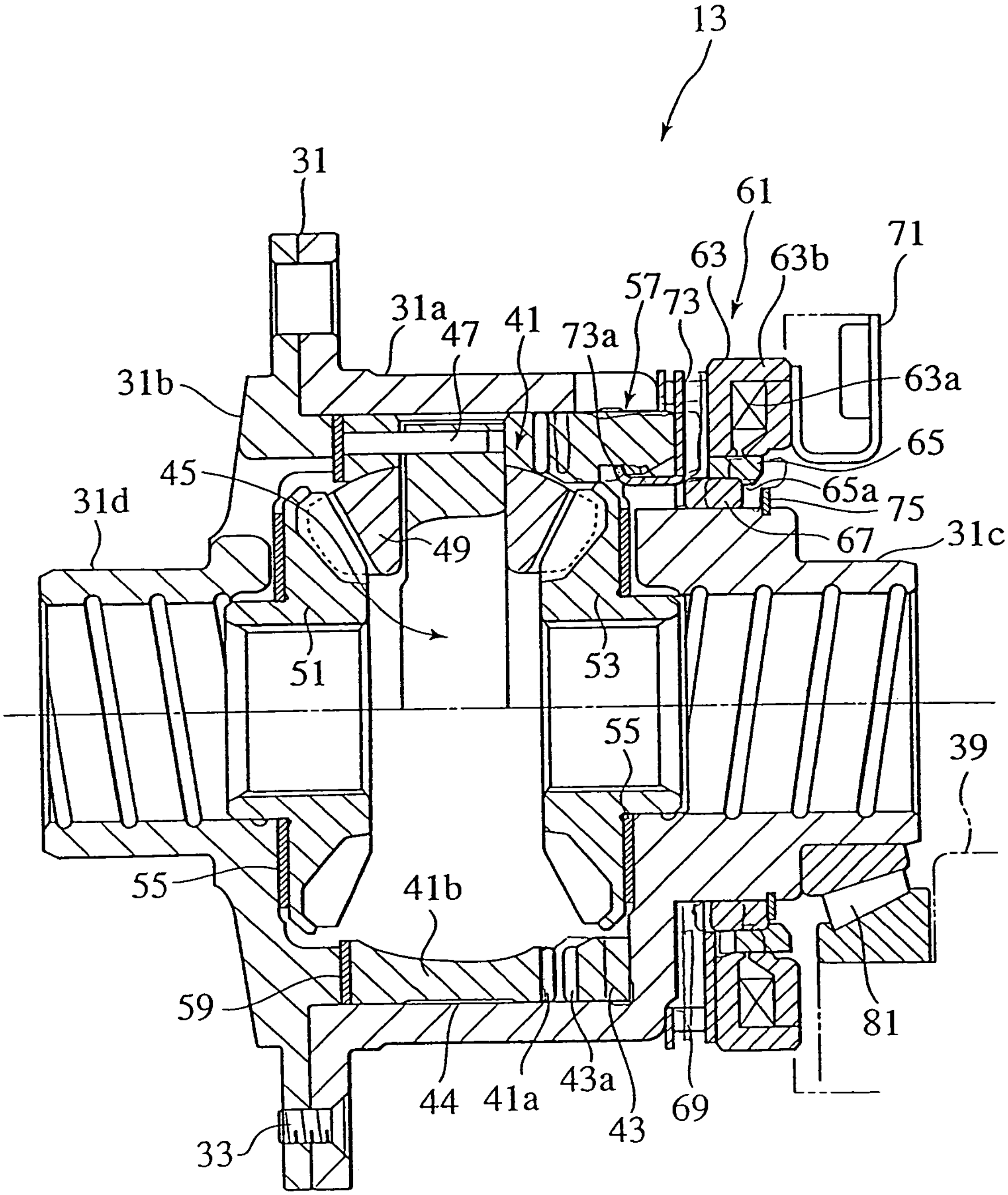


FIG.2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71
63
63b
57
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41
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31b
65
45
65a
31d
75
49
67
31c
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53
55
39
55
41b
81
59
44
41a
43a
43
69
33

FIG.3

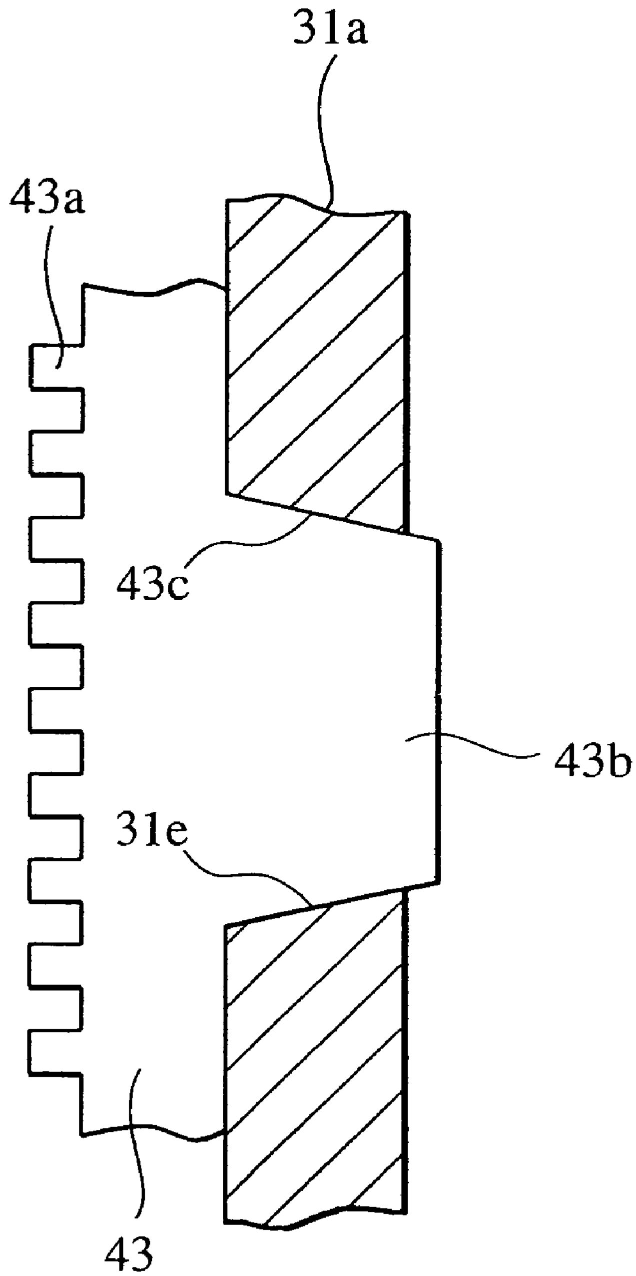
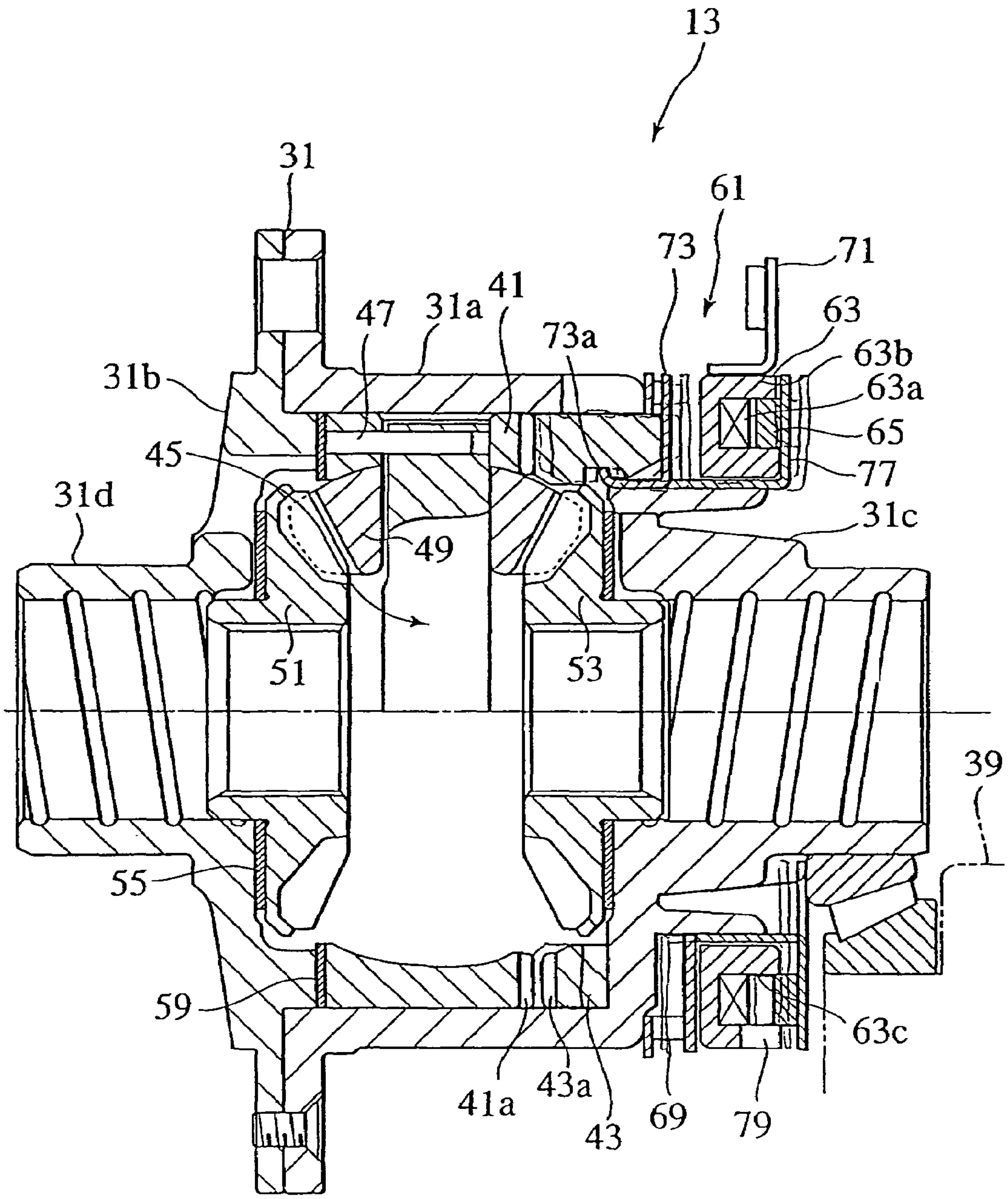


FIG.4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73a
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31b
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65
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31d
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31c
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59
63c
41a
43a
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69
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FIG.5

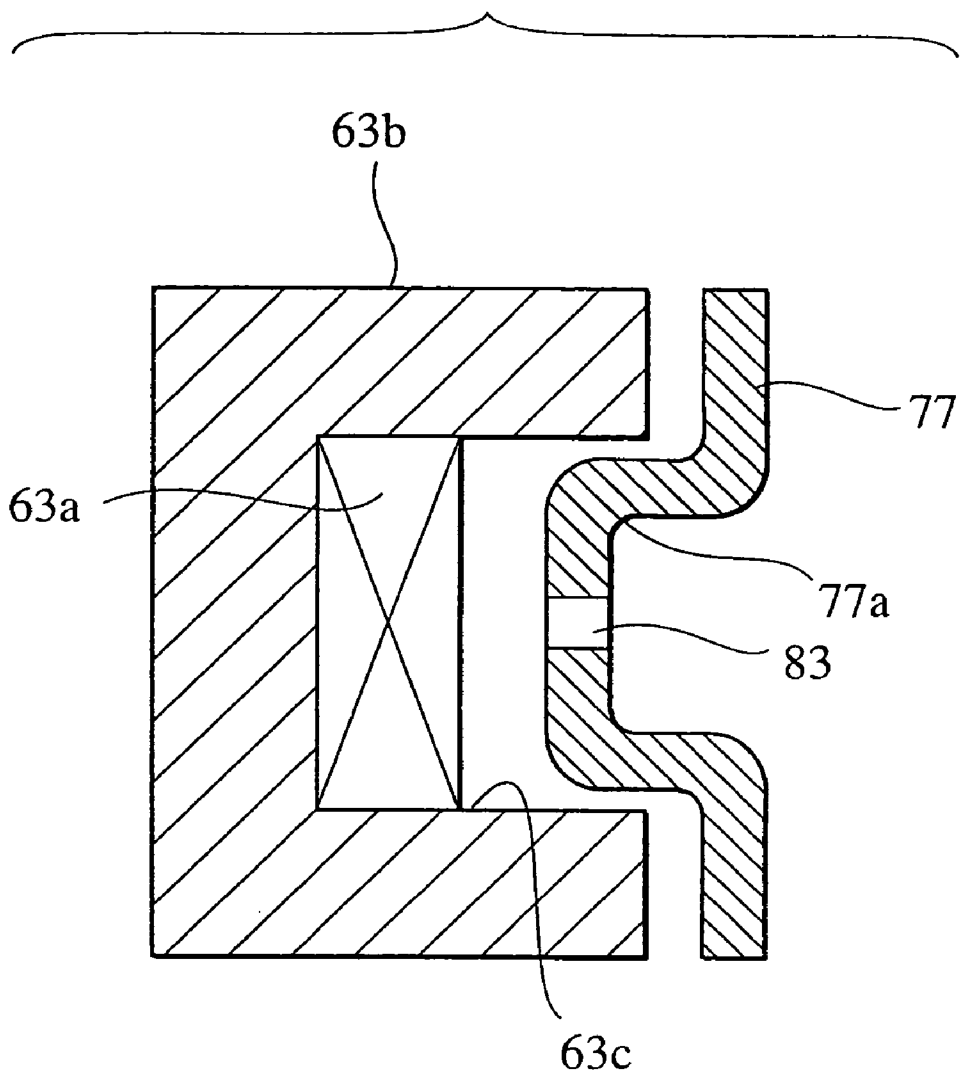

FIG.6

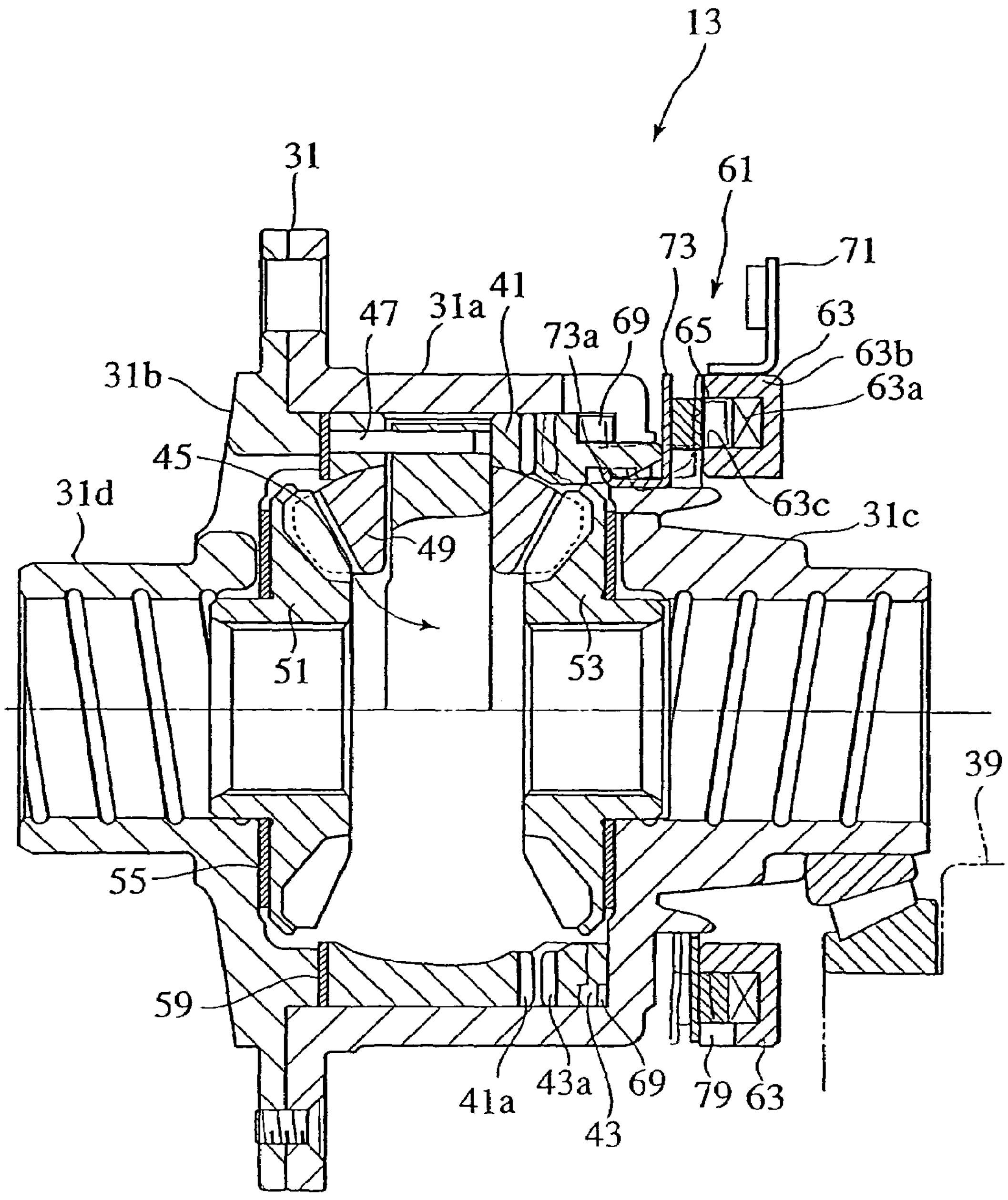
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FIG.7

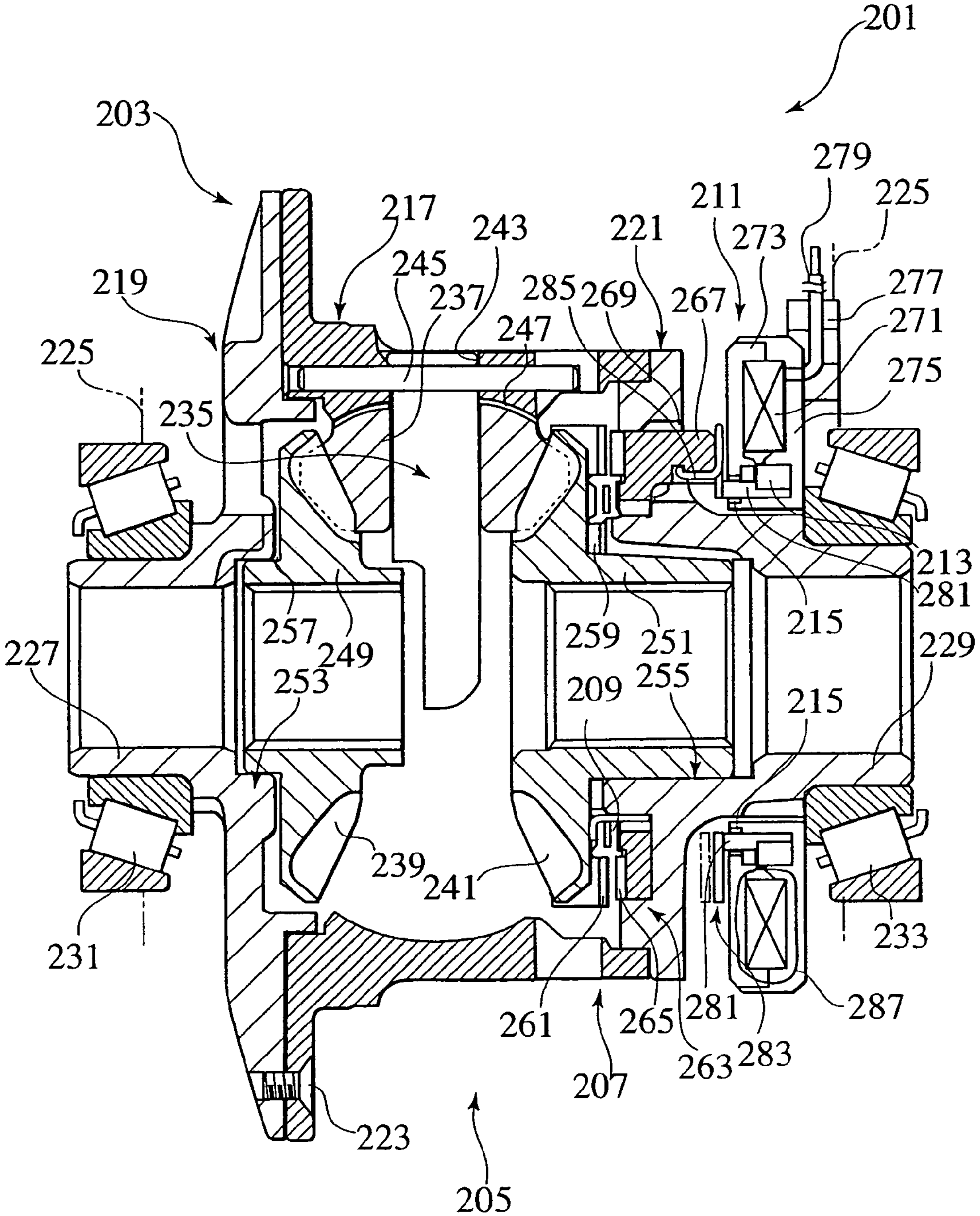
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FIG.8

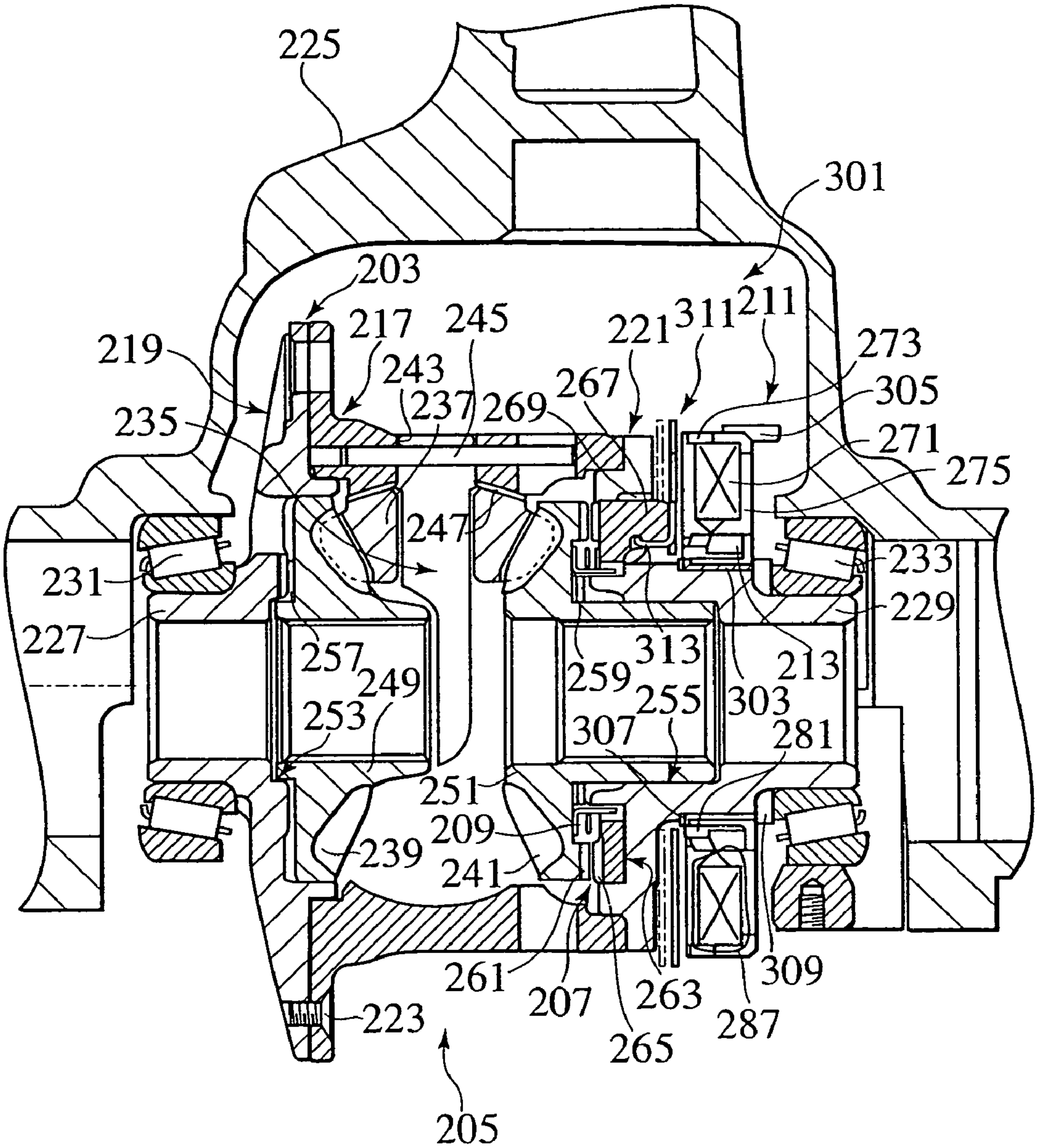

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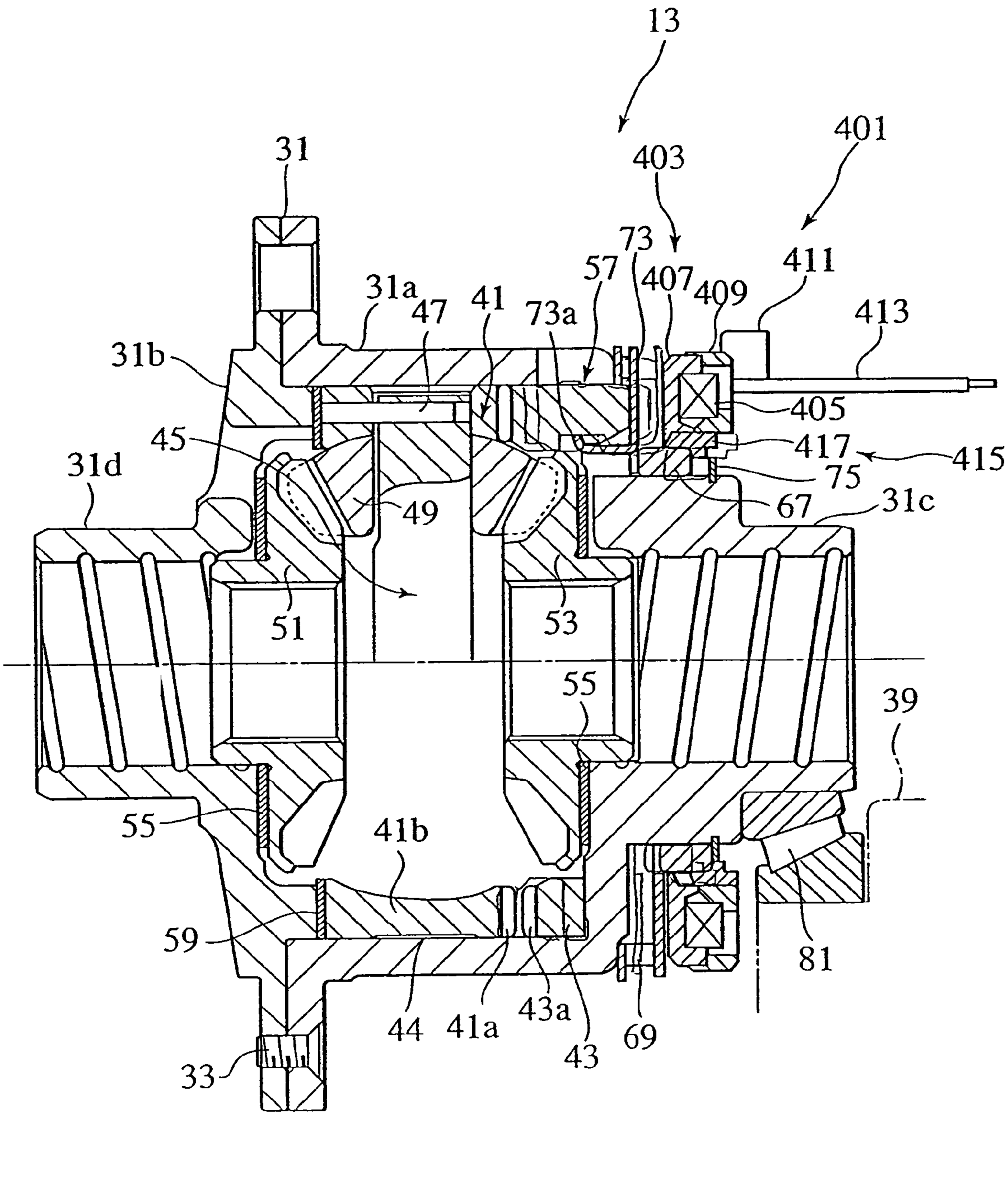
FIG.9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43
69
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FIG.10

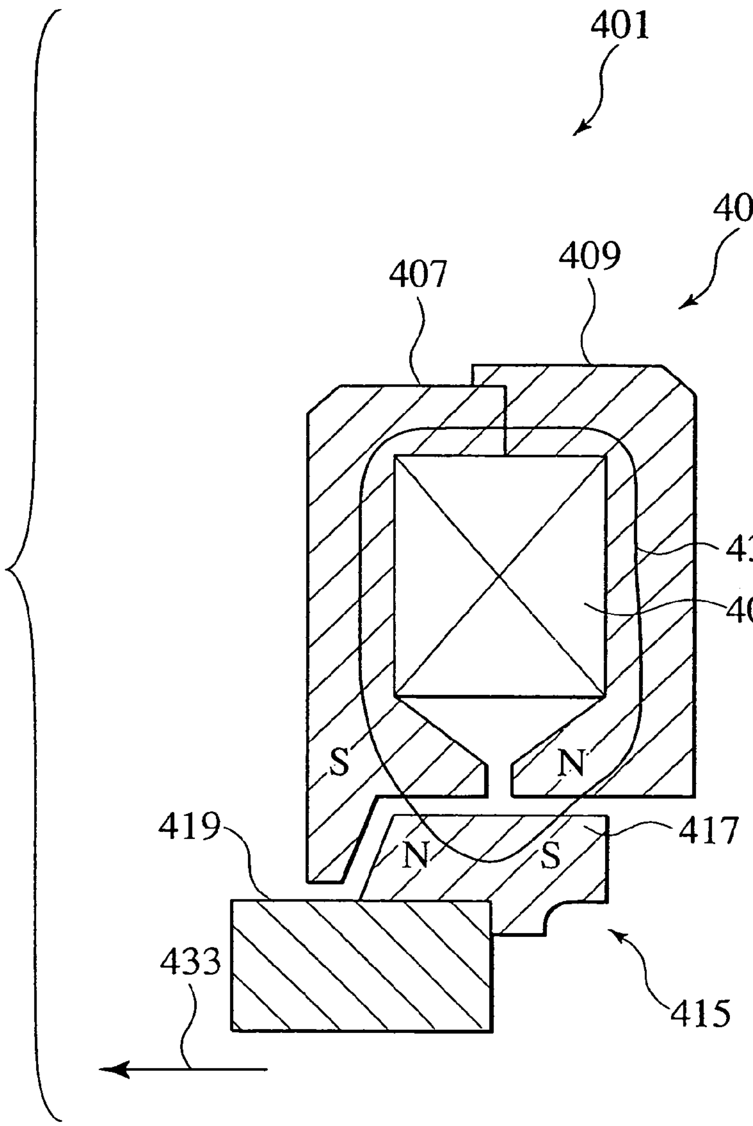


FIG.11

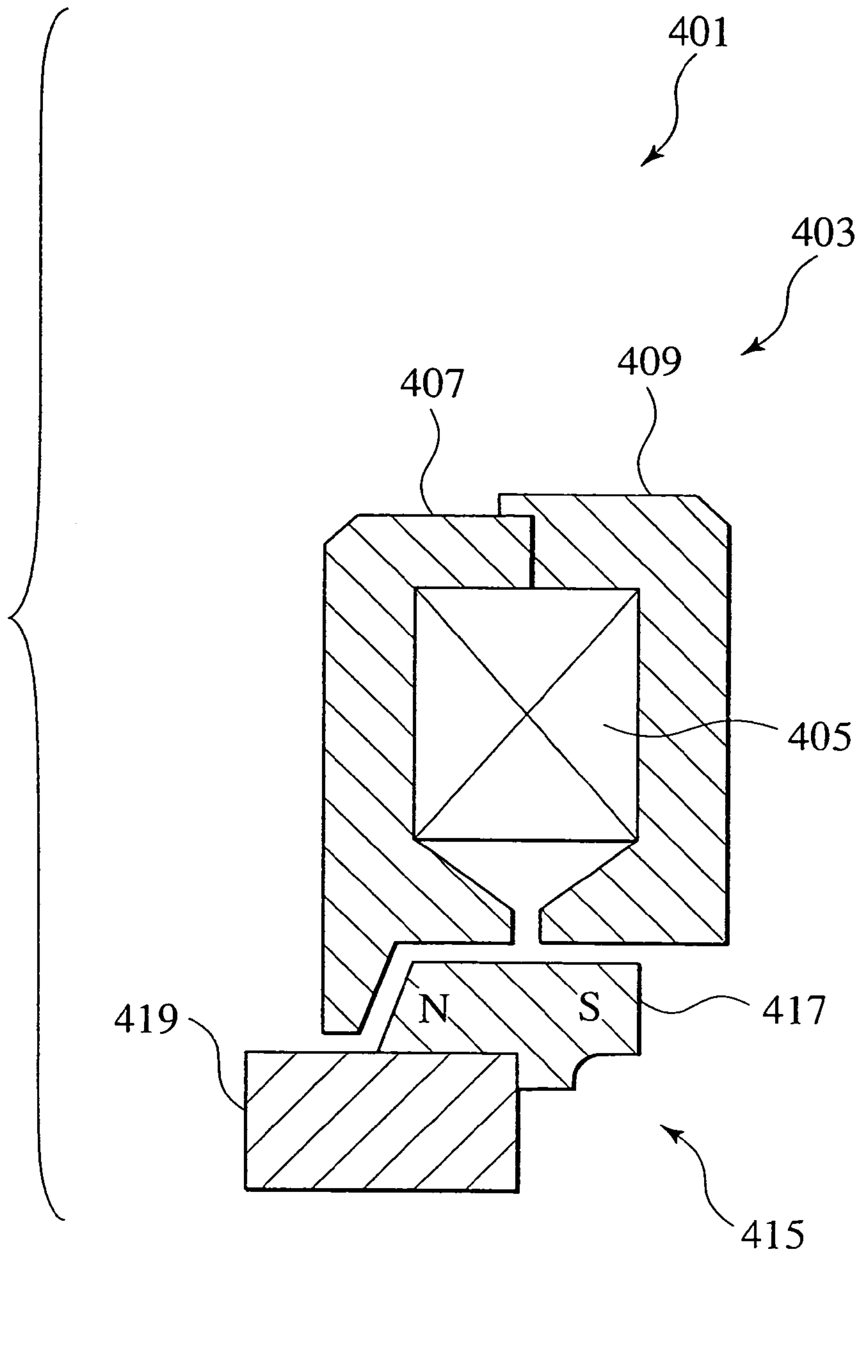


FIG.12

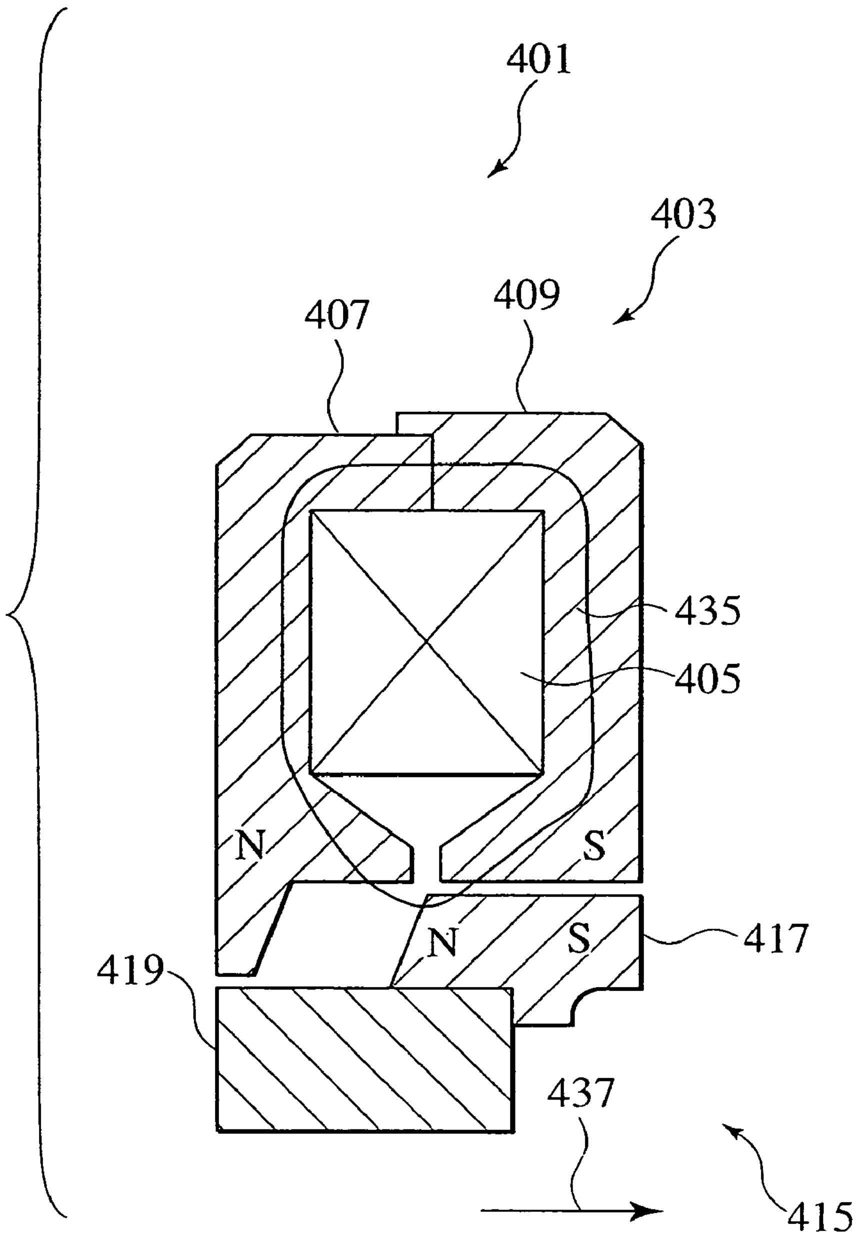
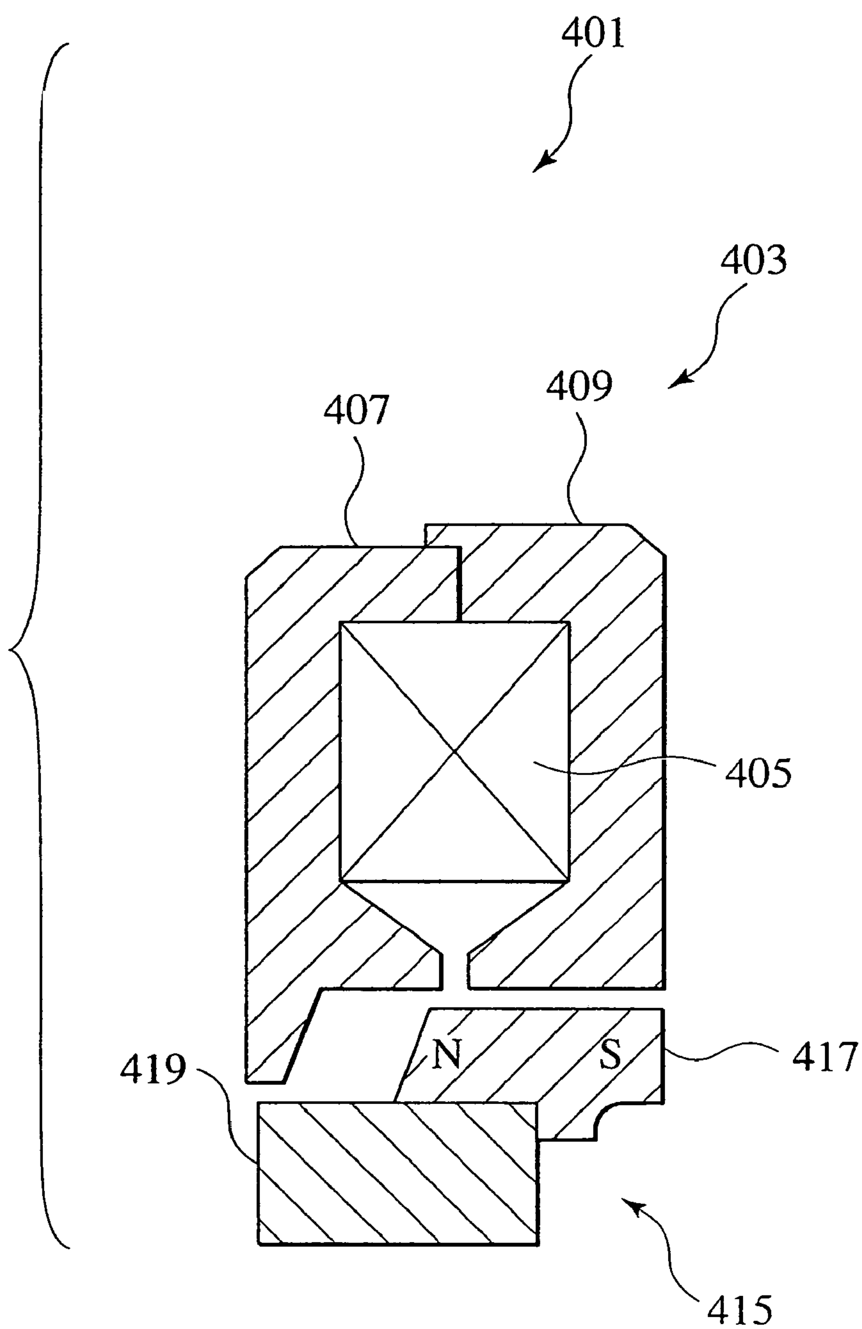


FIG.13



DIFFERENTIAL GEAR MECHANISM

CROSS REFERENCE TO RELATED APPLICATION

This application is a division of application Ser. No. 10/121,154 filed on Apr. 10, 2002, now U.S. Pat. No. 6,945,895, the entire contents of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to a differential gear mechanism applied to automobiles whose transmission and intermission of torque is controlled by an electromagnetic means.

2. Description of the Related Art

Japanese Patent Examined Application (Kokoku) No. 5-54574 discloses a proposed differential gear mechanism. The differential gear mechanism includes a differential gear, a drivable sleeve having a first clutch, and a rotatable outer case driven by torque from an engine. The outer case is further provided with a second clutch which is to be engaged with the first clutch thereby the torque is transferred from the engine to the differential gear. A part-time 4WD automobile having the differential gear mechanism has two driving mode of 4 WD and 2 WD.

SUMMARY OF THE INVENTION

The above described proposed differential gear mechanism needs a cylinder driven by hydraulic pressure of oil or air to drive the sleeve. The hydraulic or pneumatic cylinder is a relatively large apparatus compared with the differential gear so that the differential gear mechanism comes to be large.

A shift fork extended from the cylinder is slidably engaged with the sleeve. During the gear is rotating, the shift fork has to slide in contact with the sleeve so that the torque generated by the engine is exhausted and the output torque is affected by the sleeve movement.

The present invention has a purpose of providing a compact differential gear mechanism whose transmission and intermission of torque can be controlled with small reduction of the torque.

To solve the problem, the inventors get an idea of a compact electromagnetic actuator with a small electrical consumption and thought to apply the electromagnetic actuator to a differential gear mechanism. The present invention is completed by designing a suitable structure of the differential gear mechanism with the electromagnetic actuator.

A differential gear mechanism according to the present invention includes a rotatable case driven by torque from an engine, a differential gear set housed in the case for differential distribution of the torque to a pair of output axes, comprising a first clutch, an annular plunger movable in a direction of the rotation axis and an annular electromagnetic actuator for actuation of the plunger in the direction of the rotation axis. The case further comprises a second clutch being slidable in the direction of the rotation axis and the second clutch is actuated by the plunger so as to be engaged with the first clutch. Thereby the differential gear set is locked or the torque is transmitted to the differential gear set.

According to the constitution described above, the annular plunger is slidably contact with the annular second clutch in the rotating surface and the plunger pushes to actuate the second clutch. In contrast with the above described proposed differential gear mechanism whose shift fork and sleeve are engaged with each other and slide in its rotation direction, the output torque is less affected by the sliding friction drag. Therefore the electromagnetic actuator can be constituted smaller so that the differential gear mechanism comes to be compact. Sealing member can be omitted because hydraulic or pneumatic drives are needless to the mechanism, thereby the differential gear mechanism further comes to be compact. Furthermore the omission of the hydraulic or pneumatic drives assures the stable working in a case where the external pressure changes in a use at a high ground.

The differential gear mechanism according to the present invention more preferably includes a nonmagnetic annular member between the plunger and the second clutch, and a spring for applying a force to the annular member in a counter direction to a driving direction of the electromagnetic actuator.

According to the constitution described above, the electromagnetic actuator is constituted to drive the plunger only in one direction so as to be compact. The spring always applies a force to the annular member in the counter direction, thereby the annular member keeps its state in a case of the electromagnetic actuator failure. Therefore severe troubles such as the gear breakage happen hardly. Furthermore the magnetism leakage from the electromagnetic actuator is diminished and high electric efficiency is accomplished because the annular member is made of nonmagnetic material. The plunger is driven by smaller electric power.

The electromagnetic actuator according to the present invention further preferably includes an annular solenoid and a core surrounding the solenoid to leave a gap. The core and the plunger form a closed magnetic circuit.

According to the constitution described above, the magnetism forms a closed circuit so as to further diminish the leakage thereof. Therefore further higher electric efficiency is accomplished and the plunger is driven by smaller electric power.

The plunger is preferably constituted from a permanent magnet magnetized in its driving direction. The plunger can be driven bi-directionally by a current applied to the solenoid so that the spring can be omitted. Thereby the differential gear mechanism can be constituted more compact. The plunger keeps its position by a magnetic force thereof when the current applied to the solenoid is cut. The electric power can be saved because continuous excitation of the magnetism is needless. Furthermore severe troubles such as the gear breakage happen hardly in a case of the electromagnetic actuator failure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a plan view showing an automobile provided with a differential mechanism according to a first embodiment of the present invention;

FIG. **2** is a cross-sectional view showing the differential mechanism according to the first embodiment of the present invention;

FIG. **3** is a cross-sectional view showing an engaging state of the clutch and the outer case according to the first embodiment of the present invention;

FIG. **4** is a cross-sectional view showing the differential mechanism according to a second embodiment of the present invention;

FIG. **5** is a cross-sectional view showing the differential mechanism according to a modification of the second embodiment of the present invention;

FIG. **6** is a cross-sectional view showing the differential mechanism according to a third embodiment of the present invention;

FIG. **7** is a cross-sectional view showing the differential mechanism according to a fourth embodiment of the present invention;

FIG. **8** is a cross-sectional view showing the differential mechanism according to a fifth embodiment of the present invention;

FIG. **9** is a cross-sectional view showing the differential mechanism according to a sixth embodiment of the present invention;

FIG. **10** is a cross-sectional view showing an excited state of the electromagnet according to the sixth embodiment of the present invention;

FIG. **11** is a cross-sectional view showing suspension of the electromagnet excitation after the state shown in FIG. **10** according to the sixth embodiment of the present invention;

FIG. **12** is a cross-sectional view showing an excited state of the electromagnet whose excitation direction is reversed to the state shown in FIG. **10** according to the sixth embodiment of the present invention;

FIG. **13** is a cross-sectional view showing suspension of the electromagnet excitation after the state shown in FIG. **12** according to the sixth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[First Embodiment]

The first embodiment of the present invention will be described below with reference to FIG. **1** to FIG. **3**.

As shown in FIG. **1**, a torque of an engine **1** (a power source) is shared to rear wheels **7** and front wheels **9** via a transmission **3** and a power changeover device **5**. The driving force to the front wheels **9** is inputted to a front differential **13** via a propeller shaft **11**, and further, is shared to right and left front axles **15** so that the front wheels **9** are driven. On the other hand, the driving force to the rear wheels **7** is inputted to a rear differential **19** via a propeller shaft **17**, and further, is shared to right and left rear axles **21** so that the rear wheels **7** are driven. As shown in FIG. **2**, an outer case **31** (a first rotation body) of the front differential **13** is constructed in a manner that a case **31***a* and a cover **31***b* are fixed by a bolt **33**. A ring gear **35** (see FIG. **1**) is fixed to the outer case **31**, and the driving force of the engine **1** is inputted to the ring gear **35** via a drive pinion so that the ring gear **35** is driven.

Further, the outer case **31** is rotatably supported in a stationary differential carrier **39** (see FIG. **1**) by boss portions **31***c* and **31***d* at its both ends. In order to rotatably support the outer case **31** to the differential carrier **39**, tapered roller bearings **81** are interposed between the boss portions **31***a* and **31***d* and the differential carrier **39**.

A substantially short-cylindrical inner case **41** (a second rotation body) is provided coaxially with the case **31***a* so that it is rotatably supported in the inner periphery of the case **31***a*. The outer periphery of the inner case **41** is formed with an annular recess **44**, and is supported to the case **31***a* at both sides of the annular recess **44**. Moreover, a substantially short-cylindrical clutch **43** is arranged on the right side of the inner case **41**.

Engaging and separable radial dog clutches **41***a* and **43***a* are formed between the inner case **41** and clutch **43**, that is, the opposing surface between both members **41** and **43**. Gear teeth of the dog clutches **41***a* and **43***a* are tapered so that they can be easily engaged with each other.

In the inner case **41**, a pinion shaft **45** is integrated by a spring pin **47** so as to be perpendicular to its rotating axis. Two pinion gears **49** (one of them is not shown in FIG. **2**) are rotatably arranged on the pinion shaft **45**, and are engaged with a pair of opposing side gears **51** and **53**.

An inner surface **41***b* of the inner case **41** receives a thrust of the pinion gear **49**. Further, a washer **55** is interposed between the side gear **51** and the outer case **31** and between the side gear **53** and the outer case **31** so as to receive a thrust of the side gears **51** and **53**. Further, a receiving washer **59** is interposed between the left end face of the inner case **41** and the opposing surface of the outer case **31** so as to receive a thrust of the clutch **43** when the dog clutch **43***a* engages with the dog clutch **41***a*.

The side gears **51** and **53** are spline-connected to the front axle **15** shown in FIG. **1**. In the above manner, a differential gear set **57** is composed of the inner case **41**, the pinion gear **49** and the side gears **51** and **53**, and is not directly connected with the outer case **31** containing the above-mentioned members.

As shown in FIG. **3**, the clutch **43** has four projected trapezoidal legs **43***b*, which are formed at equal intervals in the circumferential direction, at the end face (right end face) having no dog clutch **43***a*. The side surface **43***c* of the projected trapezoidal leg **43***b* is tapered toward the outside of the axial direction (right side in FIG. **3**).

On the other hand, the right end wall of the case **31***a* of the outer case **31** is formed with a trapezoidal hole **31***e* at the position corresponding to the trapezoidal leg **43***b* of the clutch **43**. By doing so, the trapezoidal legs **43***b* are fitted into the trapezoidal holes **31***e* in the axial direction, and then, the circumferential side surface **43***c* of the trapezoidal legs **43***b* is abutted against the edge of the trapezoidal hole **31***e*; therefore, the clutch **43** is always rotated integrally with the outer case **31**. The edge of the trapezoidal hole **31***e* is inclined in parallel with the inclination of the circumferential side surface **43***c* of the leg **43***b*, as shown in FIG. **3**.

Accordingly, when the outer case **31** rotates and drives the clutch **43**, the clutch **43** is pushed to the inner case **41** side (left side of FIG. **2**) by the inclination of the circumferential side surface **43***c* of the leg **43***b*, so that the dog clutches **41***a* and **43***a* can be readily engaged with each other. In this manner, the clutch **43** is fitted in the outer case **31** so as to be movable to the axial direction.

A right-hand outer side of the outer case **31** is provided with an electromagnetic actuation means **61**. The electromagnetic actuation means **61** includes an electromagnet **63**, a plunger **65**, an annular member **67** and a return spring **69**.

The electromagnet **63** has a solenoid **63***a* and a core **63***b* arranged outside the solenoid **63***a*, and is fixed to a vehicle body side by a bracket **71** leaving a gap between the bracket **71** and the vehicle body so that leakage of the magnetic field to the vehicle body is prevented. Further, the electromagnet **63** is formed as a whole into a shape of ring surrounding the right-hand boss portion **31***c* of the case **31***a* and the core **63***b* is formed to have an annular gap facing to the rotation axis.

The plunger **65** is formed into a shape of ring, and arranged on the inner peripheral side of the electromagnet **63** facing to the annular gap of the core **63***b* to form a magnetic path with the core **63***b*. An annular member **67** is attached to the inner peripheral surface of the plunger **65** in a state of being engaged with there. More specifically, the inner peripheral surface of the plunger **65** is formed with a projection **65***a*, and the annular member **67** is engaged with the projection **65***a* to be positioned regarding to the axis direction. By doing so, the plunger **65** is positioned outside the annular member **67** coaxially with the annular member **67**.

The entirety of the annular member **67** is made of a non-magnetic material. Further, the annular member **67** contacts with the outer peripheral surface of the boss portion **31***c* of the case **31**, and thereby, is positioned coaxially with the boss portion **31***c*. The plunger **65** is in a state of being engaged with the outer periphery of the annular member **67**; therefore, the plunger **65** is indirectly positioned coaxially with the boss portion **31***c* via the annular member **67**.

As described above, the electromagnet **63**, the plunger **65** and the annular member **67** are all formed into the shape of ring, and the annular member **67** is indirectly positioned coaxially with the boss portion **31***c* of the case **31***a*. By doing so, the electromagnetic actuation means **61** has a structure of being inserted in the boss portion **31***c* and coaxial with the front axle **15** (see FIG. **1**) spline-connected to the side gear (boss portion?) **53** of the inner case **41**.

Further, the annular member **67** is capable of reciprocating to the axial direction of the boss portion **31***c* in a state of contacting with the outer peripheral surface of the boss portion **31***c*. In order to prevent the annular member **67** from coming off the boss portion **31***c* by the reciprocation, the boss portion **31***c* is attached with a stopper plate **75**.

Moreover, a retainer **73**, which is abutted against the leg **43***b* (see FIG. **3**) of the clutch **43**, is interposed between the annular member **67** and the clutch **43**. The retainer **73** is abutted against the leg **43***b* of the clutch **43**, and thereby, pushing and moving the dog clutch **43** to the engaging direction of the dog clutches **43***a* and **41***a*.

Further, the retainer **73** is bent to the axial direction of the clutch **43**, and is extended upwardly. By doing so, the retainer is formed with a latch **73***a*, which is engaged with a recess **43***e* of the clutch **43**. As described above, the latch **73***a* is engaged with the clutch **43**, and thereby, the retainer **73** takes the clutch **43** to the same direction when moving to a direction separating from the inner case **41**; therefore, it is possible to release the engagement of the dog clutches **41***a* and **43***a*.

The return spring **69** is interposed between the retainer **73** and the case **31***a* of the outer case **31** so as to urge the retainer **73** to a direction of releasing the engagement of the dog clutches **41***a* and **43***a*. Thus, when the electromagnet **63** is not driven, the engagement of the dog clutches **41***a* and **43***a* is released by the return spring **69**.

The upper half side of FIG. **2** shows a state that the dog clutches **41***a* and **43***a* are engaged with each other; on the other hand, the lower half side of FIG. **2** shows a state that the dog clutches **41***a* and **43***a* are separated from each other.

When a current is applied to the electromagnet **63**, a magnetic path passing through the core **63***b* and the plunger **65** is formed, and then, the plunger **65** is moved to the left-hand side in the axial direction. By the movement, the annular member **67** engaging with the plunger **65** is integrally moved to the same direction as above, and thereby, the annular member **67** pushes the retainer **73**. By doing so, the clutch **43** is moved to the left-hand direction, and then, the dog clutch **43***a* of the clutch **43** is engaged with the dog clutch **41***a* of the inner case **41**. Thus, the outer case **31** and the inner case **41** provided therein are integrally rotated via the clutch **43**. In this case, the receiving washer **59** receives a thrust of the inner case **41** when the dog clutches **41***a* and **43***a* are engaged with each other because it contacts with these dog clutches.

When the current application to the electromagnet **63** is stopped, the retainer **73** is moved to the left-hand side in the axial direction by the urging force of the return spring **69** together with the clutch **43**. For this reason, the engaging dog clutches **41***a* and **43***a* are separated from each other. Therefore, the outer case **31** and the inner case **41** provided therein are rotatable independently from each other.

In the case of this vehicle, when the driving state is changed from a four-wheel driving state to a two-wheel driving state by the electromagnetic actuator **61** according to the present invention, the driving force from the engine to the front wheel side is cut off by the power changeover device **5**. Then, the driving force of the engine **1** is used to drive only rear wheels **7** via the propeller shaft **17** and the rear differential **19**.

Thereafter, so long as the two-wheel driving state is kept, the differential gear set **57** of the front differential **13** has idling by the front wheels **9** via the driving path reverse to the four-wheel driving so far. In this case, however, with the changeover to the two-wheel drive, the engagement of the dog clutches **41***a* and **43***a* is released by the return spring **69**, so that the clutch **43**, the outer case **31** and the ring gear **35** have no idling. Therefore, it is possible to reduce an energy loss and the generation of noise by the running resistance of these idling members.

According to the above first embodiment, the electromagnetic actuation means **61** has the structure of moving the clutch **43** to the axial direction so that the dog clutches **41***a* and **43***a* are disconnected and connected, and the driving state is changed by controlling the current application; therefore, it is possible to miniaturize an actuator. Further, there is no need of considering a fluid leakage, and no seal member for preventing the fluid leakage is required, so that the number of components can be reduced, the structure can be simplified, and assembling can be readily performed.

The core **63***c* and the plunger **65** compose a closed magnetic circuit so that magnetic loss by leakage of the magnetic field from the electromagnet **63** to the outer case **31** is minimized. Thereby the electric power to switch the driving mode is saved.

Further, there is no need of providing sliding parts such as actuator driving by fluid pressure; therefore, it is possible to reduce a sliding resistance, and an influence to output torque.

Further, the electromagnetic actuation means **61** is formed into the shape of ring so that it is arranged coaxially with the front axle **15**; therefore, it is possible to apply the driving force from the entirety of the ring shape. As a result, the clutch **43** can be driven by a great force, and a stable drive can be performed. In addition, in the above ring shape, the layout passing the front axle **15** is possible; therefore, a preferable balance can be obtained.

Moreover, according to the above first embodiment, the inner peripheral surface of the plunger **65** is provided with the annular member **67** made of non-magnetic material, and thereby, the plunger **65** made of magnetic material has no contact with the outer case **31**, the retainer **73** and the like. Therefore, the magnetic path can be formed at the shortest distance without leaking a magnetic force. As described above, no leakage of the magnetic force is generated; therefore, it is possible to effectively form the magnetic path. As a result, there is no need of making large a current supplied to the electromagnetic actuation means **61**, so that power saving can be achieved.

Further, the plunger **65** is coaxially positioned by the annular member **67**; therefore, the structure for positioning the plunger **67** can be simplified.

Further, the annular member **67** is coaxially positioned by the boss portion **31***c* of the outer case **31**; therefore, no member for positioning the annular member is required, and the structure can be simplified and miniaturized.

[Second Embodiment]

The second embodiment of the present invention will be described below with reference to FIG. **4**. In this second embodiment, the same elements as the above first embodiment are referenced with the same numerals and the detailed descriptions are omitted. Mainly differences are described below.

In this second embodiment, the core **63***b* of the electromagnet **63** of the electromagnetic actuation means **61** is formed into a shape of U-letter in its cross section, and has an opening at the end face on the position separating from the clutch **43**. Further, the retainer **73** is formed integrally with a support plate **77**, which extends to a direction far from the clutch **43**. The support plate **77** is attached with the plunger **65**.

The plunger **65** is formed into a shape of ring, and is fixed to the surface on the clutch **43** side of the support plate **77**. Further, the plunger **65** is formed into a dimension capable of coming in and out the aperture **63***c* of the core **63***b*, and is fixed to the support plate **77** so as to correspond to the position of the aperture **63***c*.

In addition, the core **63***b* is partially formed with a drain hole **79** for air or oil vent.

The return spring **69** is interposed between the retainer **73** and the case **31***a* of the outer case **31**, and is used for urging the retainer **73** to a direction of releasing the engagement of the dog clutches **41***a* and **43***a*. Therefore, when the electromagnet **63** is not driven, the dog clutches **41***a* and **43***a* are disconnected by the return spring **69**.

The upper half side of FIG. **4** shows a state (four-wheel driving state) that the dog clutches **41***a* and **43***a* are engaged with each other; on the other hand, the lower half side of FIG. **4** shows a state (two-wheel driving state) that the dog clutches **41***a* and **43***a* are separated from each other.

When a current is applied to the electromagnet **63**, a magnetic path passing through the core **63***b* and the plunger **65** is formed, and then, the plunger **65** is moved to the left-hand side in the axial direction. By the movement, the support plate **77** and the retainer **73** fixing the plunger **65** is integrally moved to the same direction as above. By doing so, the clutch **43** is moved to the left-hand direction, and then, the dog clutch **43***a* of the clutch **43** is engaged with the dog clutch **41***a* of the inner case **41**. Thus, the outer case **31** and the inner case **41** provided therein are integrally rotated via the clutch **43** (four-wheel driving state). In this case, the receiving washer **59** receives a thrust of the inner case **41** when the dog clutches **41***a* and **43***a* are engaged with each other because it contacts with these dog clutches.

When the current application to the electromagnet **63** is stopped, the retainer **73** is moved to the right-hand side in the axial direction by the urging force of the return spring **69** together with the clutch **43**. For this reason, the engaging dog clutches **41***a* and **43***a* are separated from each other. Therefore, the outer case **31** and the inner case **41** provided therein are rotatable independently from each other.

As described above, in this second embodiment, when no current is applied to the electromagnet **63**, the engagement of the dog clutches **41***a* and **43***a* is released so that the two-wheel driving state can be obtained. As the need arises, the dog clutches **41***a* and **43***a* are engaged with each other so that the four-wheel driving state can be obtained. Therefore, it is possible to keep the two-wheel driving state and to improve a running (driving) performance on the paved road even if the electromagnet **63** has a failure.

In a state that the plunger **65** comes into the aperture **63***c* of the core **63***b*, a clearance is kept between the solenoid **63***a* of the core **63***b* and the coming plunger **65**. In the structure capable of keeping the clearance, a sliding resistance becomes small; therefore, it is possible to reduce an influence to torque.

Further, in this second embodiment, no annular member **67** is provided; therefore, the number of components can be reduced, and the structure can be simplified. In addition, the structure is provided such that the plunger **65** comes into the core **63***b*; therefore, the actuating space becomes small, and miniaturization can be achieved.

FIG. **5** shows a modification example of the support plate **77** of the second embodiment.

In this modification example, the support plate **77** or the retainer **73** having the support plate **77** is formed of a magnetic material. Further, in place of the plunger **65**, the support plate **77** is formed with a projection **77***a*, which is capable of coming into the aperture **63***c*, at the position corresponding to the aperture **63***c* of the core **63***b*. Therefore, when a current is applied to the solenoid **63***a*, the projection **77***a* is moved to a direction of coming into the aperture **63***c*, and thereby, the dog clutches **41***a* and **43***a* can be engaged with each other by the above movement.

In addition, the projection **77***a* of the modification example is formed with a drain hole **83** for air or oil vent.

[Third Embodiment]

The third embodiment of the present invention will be described below with reference to FIG. **6**. In this third embodiment, the same elements as the above embodiments are referenced with the same numerals and the detailed descriptions are omitted. Mainly differences are described below.

In this third embodiment, the core **63***b* of the electromagnet **63** of the electromagnetic actuation means **61** is formed into a shape of U-letter in its cross section, and has an opening at the end face on the clutch **43** side. Further, the retainer **73** is formed with a plunger **65**, which is formed into a shape of ring.

The plunger **65** is formed into a dimension capable of coming in and out the aperture **63***c* of the core **63***b*, like the above second embodiment, and is fixed to the retainer **73** so as to correspond to the position of the aperture **63***c*.

In addition, the core **63***b* is partially formed with a drain hole **79** for air or oil vent.

The return spring **69** is interposed between the case **31***a* and the clutch **43** in the outer case **31**, and is used for urging the retainer **73** to an engaging direction of the dog clutches **41***a* and **43***a*. Therefore, when the electromagnet **63** is not driven, the dog clutches **41***a* and **43***a* are connected by the return spring **69**.

The upper half side of FIG. **6** shows a state (four-wheel driving state) that the dog clutches **41***a* and **43***a* are engaged with each other; on the other hand, the lower half side of FIG. **6** shows a state (two-wheel driving state) that the dog clutches **41***a* and **43***a* are separated from each other.

In this third embodiment, when the current application to the electromagnet **63** is stopped, the retainer **73** usages the clutch **43** to the left-hand side in the axial direction by the urging force of the return spring **69**. By doing so, the dog clutch **43***a* of the clutch **43** is kept in a state of engaged with the dog clutch **41***a* of the inner case **41**, and thus, the outer case **31** and the inner case **41** provided therein are integrally rotated via the clutch **43** (four-wheel driving state). In this case, the receiving washer **59** receives a thrust of the inner case **41** when the dog clutches **41***a* and **43***a* are engaged with each other because it contacts with these dog clutches.

When a current is applied to the electromagnet **63**, a magnetic path passing through the core **63***b* and the plunger **65** is formed, and then, the plunger **65** is moved to the right-hand side in the axial direction. By the movement, the retainer **73** fixing the plunger **65** is integrally moved to the same direction as above, and then, the clutch **43** is moved to the right-hand direction; as a result, the engaging dog clutches **41***a* and **43***a* of the clutch **43** are separated from each other. Therefore, the outer case **31** and the inner case **41** provided therein are rotatable independently from each other.

As described above, in this third embodiment, when no current is applied to the electromagnet **63**, the engagement of the dog clutches **41***a* and **43***a* are engaged with each other so that the four-wheel driving state can be obtained. As the need arises, the engagement of the dog clutches **41***a* and **43***a* is released so that the two-wheel driving state can be obtained. Therefore, it is possible to keep the four-wheel driving state and to improve a driving performance on rough road even if the electromagnet **63** has a failure.

Like the above second embodiment, in a state that the plunger **65** comes into the aperture **63***c* of the core **63***b*, a clearance is kept between the solenoid **63***a* of the core **63***b* and the coming plunger **65**. In the structure capable of keeping the clearance, a sliding resistance becomes small; therefore, it is possible to reduce an influence to torque.

Further, in this third embodiment, no annular member **67** is provided; therefore, the number of components can be reduced, and the structure can be simplified. In addition, the structure is provided such that the plunger **65** comes into the core **63***b*; therefore, the actuating space becomes small, and miniaturization can be achieved.

Further, in this third embodiment, the support plate **77** or the retainer **73** having the support plate **77** may be formed of a magnetic material, like the above second embodiment. Further, in place of the plunger **65**, the support plate **77** may be formed with a projection **77***a*, which is capable of coming into the aperture **63***c*, at the position corresponding to the aperture **63***c* of the core **63***b*.

[Fourth Embodiment]

The fourth embodiment of the present invention will be described below with reference to FIG. **7**. In this fourth embodiment, the same elements as the above embodiments are referenced with the same numerals and the detailed descriptions are omitted. Mainly differences are described below.

A differential gear mechanism **201** of this embodiment is used to front wheels side of front wheels-drive vehicle, to rear wheels-drive vehicle, or to a center differential gear.

The differential gear mechanism **201** is composed of a case **203**, a bevel gear type differential gear set **205**, a dog clutch **207**,a return spring **209**, an electromagnet **211** (electromagnetic actuation means), a plunger **213**, an O-ring **215** and the like.

The case **203** is composed of a case **217** and left and right covers **219** and **221** in which the case **217** and the left cover **219** are fixed by a bolt **223** and the case **217** and the right cover **221** are welded.

The case **203** is arranged in a differential carrier **225**, and boss portions **227** and **229** formed in covers **219** and **221** are supported to the differential carrier **225** via tapered roller bearings **231** and **233**, respectively.

The differential carrier **225** is formed with an oil reservoir. In the case **203**, a ring gear is fixed by a bolt, and the ring gear is engaged with an output gear of power transmission system. The power transmission system is connected to a transfer side, and the case **203** is rotated and driven by a driving force of engine transmitted via the transfer and the power transmission system.

The differential gear set **205** is composed of a pinion shaft **235**, a pinion gear **237** supported on the pinion shaft **235**, and output side gears **239** and **241**.

The pinion shaft **235** has one end portion, which is fitted into a through hole **243** formed in a case **217**, and is fixed by a spring pin **245**. The side gears **239** and **241** are engaged with the pinion gear **237** from left and right.

A spherical washer **247** is interposed between the case **203** and the pinion gear **237**, and is used for receiving a centrifugal force of the pinion gear **237** and an engagement reaction force generated by the engagement of the side gears **239** and **241**.

The boss portions **249** and **251** of the side gears **239** and **241** are supported by supports **253** and **255** formed in the covers **219** and **221**, respectively, and are connected to right and left wheels via the spline-connected axle.

A thrust washer **257** is interposed between the left side gear **239** and the case **203** so as to receive an engagement thrust of the side gear **239**; on the other hand, a thrust washer **259** is interposed between the right side gear **241** and the case **203** so as to receive an engagement thrust of the side gear **241**.

A dog clutch **207** is composed of gear teeth **261** formed in the right side gear **241**, and gear teeth **265** formed in a clutch ring **263**.

The clutch ring **263** is formed with leg portions **267** at equal intervals in the circumferential direction. Further, the clutch ring **263** is self-locked in the case **203** in a manner that the leg portions **267** are fitted into the openings **269** formed in the cover **221** at equal intervals in the circumferential direction, and thus, is arranged so that it is freely movable in the axial direction.

When the clutch ring **263** is moved to the left side, the dog clutch **207** is engaged with there so that the differential motion of the differential gear set **205** is locked. As shown in FIG. **7**, when the clutch ring **263** is moved to the right side, the engagement of the clutch **207** is released, and thus, the differential lock is released.

The return spring **209** is interposed between the right side gear **241** and the clutch ring **263**, and is used for urging the clutch ring **263** to the side releasing the engagement of the dog clutch **207** (right side).

The electromagnet **211** is composed of a solenoid **271** and a pair of cores **273** and **275** integrated so as to hold the solenoid from right and left.

The core **275** is fixed to the differential carrier **225** via a linkage member **277**. A wire **279** of the solenoid **271** is led to the outside of the differential carrier **225**, and is connected to an onboard battery via a controller.

A plunger **213** is made of a magnetic material, and is arranged in the cores **273** and **275** so that it is freely movable in the axial direction. The plunger **213** is formed with push portions **281** at equal intervals in the circumferential direction. Each push portion **281** penetrates through the core **273** via the O-ring **215**, and projects into the left side.

The clutch ring **263** of the dog clutch **207** pushes each push portion **281** and the plunger **213** by the urging force of the return spring **209** via a sliding plate **283**. The sliding plate **283** is connected to a rotating side clutch ring **263** by an arm **285**, and is used for absorbing a sliding motion between a stationary side plunger **213** and the push portion **281**.

A magnetic path of the electromagnet **211** is formed by the cores **273** and **275** and the plunger **213**, and the plunger **213** functions as an armature. The electromagnet **211**, the core **75**, the plunger **213** and the clutch ring **263** substantially have the same constitutions and the same functions as those of the second embodiment and the details are referenced to the descriptions of the second embodiment.

The controller carries out the control for excitation to the electromagnet **211** and excitation stop.

When the electromagnet **211** is excited, a magnetic loop **287** is generated in the magnetic path, and then, the plunger **213** is moved to the left side while warping the return spring **209**. By doing so, the clutch ring **263** is moved so as to engage with the dog clutch **207**, so that the differential motion of the differential gear set **205** can be locked as described above.

During the driving on rough road, that is, under the condition that right and left driving wheels are easy to idle, when the differential motion is locked, the driving force is prevent from releasing from the idling wheel; as a result, escape from rough road and running through performance can be improved.

On the other hand, when the excitation to the electromagnet **211** is stopped, the clutch ring **263** and the plunger **213** are returned to the right side by the return spring **209**, so that the engagement of the dog clutch **207** can be released.

According to the above fourth embodiment, the electromagnet **211** has the structure of moving the clutch ring **263** to the axial direction so that the dog clutch **207** is disconnected and connected, and the driving state is changed by controlling the current application; therefore, it is possible to miniaturize an actuator. Further, there is no need of considering a fluid leakage, and no seal member for preventing the fluid leakage is required, so that the number of components can be reduced, the structure can be simplified, and assembling can be readily performed.

Further, there is no need of providing sliding parts such as actuator driving by fluid pressure; therefore, it is possible to reduce a sliding resistance, and an influence to output torque.

Further, the electromagnet **211** is formed into the shape of ring so that it is arranged coaxially with the differential gear mechanism **201**; therefore, it is possible to apply the driving force from the entirety of the ring shape. As a result, the clutch ring **263** can be driven by a great force, and a stable drive can be performed. In addition, in the above ring shape, the layout passing the axle is possible; therefore, a preferable balance can be obtained.

Moreover, according to the above fourth embodiment, the plunger **213** is contained in the cores **273** and **275** of the electromagnet **211**, and the cores **273** and **275** supported to the differential carrier **225** has no contact with the case **203**. Therefore, the magnetic path can be formed at the shortest distance without leaking a magnetic force.

Further, as described above, no leakage of the magnetic force is generated; therefore, it is possible to effectively form the magnetic path. As a result, there is no need of making large a current supplied to the electromagnet **211**, so that the battery power can be saved.

Further, the plunger **213** is supported by the cores **273** and **275** of the electromagnet **211**; therefore, it is possible to readily carry out clearance adjustment between the cores **273**; **275** and the plunger **213**. As a result, it is possible to reduce a magnetic force loss between these members and a sliding resistance to the minimum limit.

Further, the plunger **213** is coaxially positioned by the cores **273** and **275**; therefore, the plunger **213** can be positioned with a simple structure.

Further, no contamination such as magnetic metal powder contained in the oil is attracted to the solenoid **271** by the O-ring **215** interposed between the core **273** and the plunger **213**. Therefore, it is possible to prevent a failure of the movement of the plunger **213** and a failure of the operation of the dog clutch **207** in the case where the magnetic metal powder jams; as a result, a normal operation can be maintained for a long period.

Incidentally, the cores **273** and **275** may be supported to the case **203** by bearing.

[Fifth Embodiment]

The fifth embodiment of the present invention will be described below with reference to FIG. **8**. In this fifth embodiment, the same elements as the above embodiments are referenced with the same numerals and the detailed descriptions are omitted. Mainly differences are described below.

A differential gear mechanism **301** of this embodiment differs from the differential gear mechanism **201** of the fourth embodiment in that the supporting structure of the electromagnet **211** is changed.

The same numerals are given to the members having the function identical to the differential gear mechanism **201**, and then, the different point will be described below with reference to these.

The electromagnet **211** is supported to the outer periphery of the right boss portion **229** of the case **203** via a sliding bearing **303** made of non-magnetic material, and is coaxially positioned. Further, the electromagnet **211** is connected to the differential carrier **225** side via the bracket **305**, and is locked.

The electromagnet **211** is positioned in the axial direction by a snap ring **307** on the boss portion **229** and the washer **309** arranged on the left side of the tapered roller bearing **233**.

Further, the electromagnet **211** fixed to the boss portion **229** is arranged inside the projection range in the axial direction of the case **203**.

The clutch ring **263** of the dog clutch **207** is connected with a retainer **311** by its arm **313**. When the electromagnet **211** is excited, the magnetic loop **287** is generated in the magnetic path, and then, the plunger **213** pushes the clutch ring **263** to the left side via the retainer **311**. By doing so, the dog clutch **207** is engaged so that the differential motion of the differential gear set **205** can be locked.

On the other hand, when the excitation to the electromagnet **211** is stopped, the clutch ring **263**, the retainer **311** and the plunger **213** are returned back to the right side by the return spring **209**, so that the engagement of the dog clutch **207** and the differential lock can be released.

In general, in the case of fixing the electromagnet (electromagnetic actuation means) to the differential carrier and locking it, when the case moves with backlash adjustment of the ring gear fixed to the case and another gear, or by assembling error, a fluctuation occurs in the distance between the case side clutch and the differential carrier side electromagnet.

Thus, in the electromagnet stroke, a margin is required for absorbing the fluctuation in the distance between the electromagnet and the case side clutch. For this reason, the working force of the electromagnet must be made large; as a result, the electromagnet becomes a large size and heavy, and the cost increases, and in addition, a vehicle assembly performance of the differential gear mechanism is reduced.

Further, the electromagnet is made into a large size, and thereby, power consumption increases; for this reason, a load to the battery becomes high, and finally, a fuel consumption of engine is reduced.

Further, the electromagnet is made into a large size, and thereby, the bracket for fixing the electromagnet to the differential carrier needs to have a considerable high strength; as a result, the bracket becomes heavy, and the cost increases.

Further, in the case where the electromagnet is fixed and locked on the differential carrier side, there is a need of adjusting a relative position between the electromagnet on the differential carrier side and the clutch on the case side; for this reason, assembling is difficult.

However, according to this fifth embodiment, in the differential gear mechanism **301** constructed as described above, the electromagnet **211** is fixed to the case **203**. By doing so, even if backlash adjustment is made between the ring gear on the case **203** side and the power transmission system output gear engaging with the ring gear, or assembling error occurs, the electromagnet **211** is moved integrally with the case **203**; therefore, no fluctuation occurs in the distance between the dog clutch **207** and the electromagnet.

Accordingly, there is no need of providing a margin for absorbing the above distance fluctuation in the stroke of the electromagnet **211**, and making large the working force of the electromagnet **211**. Thus, this serves to prevent the electromagnet **211** from becoming large size and heavy weight, an increase of cost, and a reduction of vehicle assembly performance of the differential gear mechanism **301**.

Further, it is possible to prevent an increase of power consumption of the electromagnet **211**, an increase of load to the battery, and a reduction of fuel consumption of engine.

Further, it is possible to carry out sufficient backlash adjustment between the ring gear of the case **203** and the output gear. Therefore, the engagement of these gears is normally made, and gear noise or vibration is prevented; as a result, durability can be improved.

Further, the bracket **305** merely locks the electromagnet **211** to the differential carrier **225**; therefore, the bracket **305** requires neither function of fixing the electromagnet to the differential carrier **225** nor the strength in response to the function. As a result, it is possible to achieve weight reduction and cost reduction.

Further, the differential gear mechanism **301** has the structure in which the electromagnet **211** is fixed to the case **203** side, unlike the structure in which the electromagnet is fixed to the differential carrier. Therefore, there is no need of adjusting the relative position between the electromagnet on the differential carrier side and the clutch on the case side, and in order to lock the electromagnet, the bracket **305** may be only engaged with the differential carrier **225** in assembling. As a result, assembling is very easy.

Further, the electromagnet **211** is positioned coaxially to the case **203** via the sliding bearing **303**; therefore, there is no need of providing the annular member **67** is provided in order to position the electromagnet **211** like the above first embodiment. As a result, the number of components and the cost can be reduced, and the structure can be simplified.

Further, the electromagnet **211** is fixed to the boss portion **229**, and is arranged in the projection range in the axial direction of the case **203**, and thereby, the space is effectively used. Therefore, the differential gear mechanism **301** can be made compact size, and a vehicle assembly performance can be further improved.

[Sixth Embodiment]

The sixth embodiment of the present invention is described hereinafter with reference to FIG. **9** to FIG. **13**. In this sixth embodiment, the same elements as the above embodiments are referenced with the same numerals and the detailed descriptions are omitted. Mainly differences are described below.

The electromagnetic actuation means according to the sixth embodiment is an actuator **401** and is provided with an electromagnet **403** and a plunger **415**.

The electromagnet **403** includes a solenoid **405** and a pair of cores **407** and **409** integrally enwrapping the solenoid **405** from both sides. The core **409** shown in the right side of FIG. **9** is supported by a bracket **411** connected to a differential carrier (not shown). Wires **413** are conducted from the solenoid **405** and are connected with an in-vehicle battery via a controller.

A plunger **415** is provided with an permanent magnet **417** and a non-magnetic annular member **419** which is movably supported on the boss portion **31***c* of the outer case **31**. The permanent magnet **417** is fixed to the outer periphery of the annular member **419** and is positioned in the inner periphery of the cores **407** and **409** with a moderate air-gap therebetween so that the permanent magnet **417** may move in the axis direction.

The permanent magnet **417** is positioned coaxially with the boss portion **31***c* via the annular member **419** thereby the gap between the permanent magnet **417** and the cores **407** and **409** is easy to be regulated. The gap is optimized so that its magnetic loss is minimized.

The cores **407**, **409** and the plunger **415** compose a closed magnetic circuit. The annular member **419** composed of non-magnetic material is place in an inner periphery of the permanent magnet **417**. Therefore magnetic loss by leakage of the magnetic field from the electromagnet **403** to the outer case **31** is minimized. Thereby the electric power to switch the driving mode is saved.

In a case where the vehicle's driving mode is switched from 2 WD to 4 WD, the controller (not shown) starts the excitation of the electromagnet **403** so that the dog clutches **41***a* and **43***a* are engaged with each other, and after that, the controller suspends the excitation. In case where the vehicle's driving mode is switched from 4 WD to 2 WD, the controller starts the reverse-polarized excitation of the electromagnet **403** so that the engagement of the dog clutches **41***a* and **43***a* is canceled, and after that, the controller suspends the excitation.

The upper half of FIG. **9** shows a 4 WD state which the dog clutches **41***a* and **43***a* are engaged with each other, and the lower half of FIG. **9** shows a 2 WD state which the engagement of the dog clutches **41***a* and **43***a* is canceled.

The excitation of the electromagnet **403** polarized as shown in FIG. **10** makes a magnetic loop **431** so that the plunger **415** moves to the left as an arrow **433** shown in FIG. **10** against the urging force of return spring **69**. The plunger **415** drives the clutch **43** to the left thereby the dog clutches **43***a* and **45***a* are engaged with each other and the vehicle's driving mode is switched to 4 WD.

In a case where the excitation of the electromagnet **403** is suspended after the state described above, the magnetic force of the permanent magnet **417** keeps the position of the plunger **415** as it is where the dog clutches **43***a* and **45***a* are engaged with each other against the urging force of return spring **69** so that the vehicle's driving mode is kept 4WD.

The excitation of the electromagnet **403** polarized reversely as shown in FIG. **12** after the state shown in FIG. **11** makes a magnetic loop **435** so that the plunger **415** moves to the right as an arrow **437** shown in FIG. **12**. The plunger **415** drives the clutch **43** to the right thereby the engagement of the dog clutches **43***a* and **45***a* is canceled and the vehicle's driving mode is switched to 2 WD.

In a case where the excitation of the electromagnet **403** is suspended after the state described above, the magnetic force of the permanent magnet **417** keeps the position of the plunger **415** as shown in FIG. **13** where the engagement of the dog clutches **43***a* and **45***a* is canceled so that the vehicle's driving mode is kept 2 WD.

As described above, the vehicle's driving mode of a 4 WD state or a 2 WD state is kept as it is by the permanent magnet **417** so that the electromagnet **403** is not needed to be kept excited. Therefore loads on the electromagnet **403** and the in-vehicle battery is reduced so that the fuel-efficiency is improved.

If the actuator **401** fails, the function of the permanent magnet **417** keeps the vehicle's driving mode in the 4 WD state or the 2 WD state. For the foregoing reason, there are few possibilities of occasion of the severe accident such as a crushing of the differential mechanism.

The return spring **69** which moves the plunger **415** backward may be omitted because the electromagnet **403** can drives the plunger **415** to both the engagement position and the engagement canceling position of the dog clutches. Thereby the number of the components and the cost may be reduced.

The contents of Japanese Patent Applications No. 2001-113881 (filed Apr. 12, 2001), No. 2001-343262 (filed Nov. 8, 2001), No. 2001-53741 (filed Feb. 28, 2002) and No. 2001-354370 (filed Nov. 20, 2001) are incorporated herein by reference.

Although the invention has been described above by reference to certain embodiments of the invention, the invention is not limited to the embodiments described above. Modifications and variations of the embodiments described above will occur to those skilled in the art, in light of the above teachings. For example, though dog clutches are applied in the embodiments described above, a friction clutch such as a single or multiple disk clutch or a cone clutch may be applied. Moreover the polarization of the plunger **415** made of a permanent magnet may be reversed from the case described above. The differential gear mechanism according to the present invention may be applied to any of a front differential, a rear differential and a center differential.

What is claimed is:

1. A differential gear mechanism, comprising:

a case being capable of rotation driven by a power source around a rotation axis;

a differential gear set housed in and drivingly coupled to the case, the differential gear set including first and second output gears and being configured to differentially transmit the rotation of the case to the first and second output gears;

a clutch operable to limit and free a differential motion between the first and second output gears;

an annular plunger being movable in a direction of the rotation axis and configured to operate the clutch;

an annular member fitted to the plunger and intervening between the plunger and the clutch; and

an annular electromagnetic actuator configured to actuate the plunger in the direction of the rotation axis, the annular electromagnetic actuator comprising an annular solenoid and a core surrounding the solenoid to leave a gap, the gap being spanned by the plunger such that the core and the plunger form a closed magnetic circuit,

wherein the case further comprises a pair of boss portions supporting the output axes rotatably and the annular member is positioned coaxially with the clutch by one of the boss portions.

2. The differential gear mechanism of claim **1**, further comprising:

a spring configured to apply a force to the annular member in a counter direction to a driving direction of the electromagnetic actuator.

3. The differential gear mechanism of claim **2**, wherein the annular member is made of nonmagnetic material.

4. The differential gear mechanism of claim **2**, wherein the plunger is positioned coaxially with the clutch by the annular member.

5. The differential gear mechanism of claim **1**, wherein the electromagnetic actuator is rotatably supported by the case;

the case is rotatably housed in a differential carrier; and

the electromagnetic actuator is stopped rotating by the carrier.

6. The differential gear mechanism of claim **5**, wherein the case further comprises a pair of boss portions rotatably supported by the differential carrier; and

the electromagnetic actuator is supported by one of the boss portions and is positioned within a range where an outer periphery of the case is elongated in a direction of the output axes.

7. The differential gear mechanism of claim **1**, wherein the gap is positioned in an inner periphery of the electromagnetic actuator and the plunger is slidably fitted in the inner periphery of the electromagnetic actuator.

8. The differential gear mechanism of claim **1**, wherein:

the plunger is a permanent magnet magnetized in a driving direction of the plunger and is selectively driven between a first position and a second position by a current applied to the solenoid; and

the clutch limits the differential motion when the plunger is at the first position and frees the differential motion when the plunger is at the second position.

9. The differential gear mechanism of claim **8**, wherein:

the plunger keeps its position by a magnetic force of the plunger when the current applied to the solenoid is cut.

10. A differential gear mechanism, comprising:

a case being capable of rotation driven by a power source around a rotation axis;

a differential gear set housed in and drivingly coupled to the case, the differential gear set including first and second output gears and being configured to differentially transmit the rotation of the case to the first and second output gears;

a clutch operable to limit and free a differential motion between the first and second output gears;

an annular plunger being movable in a direction of the rotation axis and configured to operate the clutch;

an annular electromagnetic actuator configured to actuate the plunger in the direction of the rotation axis, the annular electromagnetic actuator comprising a core and a solenoid fitted to the core;

an annular member of nonmagnetic material configured to transmit movements of the plunger to the clutch, the annular member being fitted to the plunger; and a spring configured to apply a force to the annular member in a counter direction to a driving direction of the electromagnetic actuator,

wherein the plunger fits with the core such that a magnetic loop is constantly closed within the plunger and the cord.

11. The differential gear mechanism of claim **10**, wherein the annular member intervenes between the plunger and the clutch.

12. An actuator for actuation of an axially operable part configured to connect and disconnect relatively rotating members, the actuator comprising:

an annular solenoid;

an annular core surrounding the solenoid to leave a gap; and

an annular plunger driven by the solenoid to actuate the axially operable part, the plunger being coaxially and movably fitted to the core and spanning the gap of the core such that the core and the plunger form a closed magnetic circuit,

wherein the plunger is a permanent magnet magnetized in the direction where the solenoid drives the plunger and is selectively driven between a first position and a second position by a current applied to the solenoid.

13. The actuator of claim **12**, wherein the annular member is made of nonmagnetic material.

14. The actuator of claim **12**, wherein the solenoid, the core and the plunger are coaxially disposed and so dimensioned as to coaxially couple with the relatively rotating members.

15. The actuator for actuation of an axially operable part configured to connect and disconnect relatively rotating members, the actuator comprising:

an annular solenoid;

an annular core surrounding the solenoid to leave a gap;

an annular plunger driven by the solenoid and coaxially and movably fitted to the core;

an annular member of nonmagnetic material configured to transmit movements of the plunger to the axially operable part, the annular member being fitted to the plunger; and

a spring configured to apply a force to the annular member in a counter direction to a direction where the solenoid drives the plunger,

wherein the plunger fits with the core such that a magnetic loop is constantly closed within the plunger and the core.

16. The actuator of claim **15**, wherein the solenoid, the core, the plunger and the annular member are coaxially disposed and so dimensioned as to coaxially couple with the relatively rotating members.

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